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# FORMATION SAMPLING WITH LARGE-DIAMETER DRILL HOLES AT FORT RANDALL DAM SITE, SOUTH DAKOTA

BY

ROSWELL W. PROUTY

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# FORMATION SAMPLING WITH LARGE-DIAMETER DRILL HOLES AT FORT RANDALL DAM SITE, SOUTH DAKOTA[1]

By Roswell W. Prouty[2]

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2/ Mining engineer, Bureau of Mines.



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## FOREWARD

The practicability of using large-diameter drill holes in certain phases of mining has long been recognized, and the practice has been successfully adapted to the sinking of airways, escapeways, shafts, and for other purposes where circular openings 36 to 60 inches in diameter will suffice.

Because of the character and large volume of core obtainable by large-diameter drilling, the practice has found some application in sampling of mineral deposits. However, the cost of such work generally limits its application, and drill holes with diameters smaller than 36 inches are used more commonly for this purpose. This practice is followed in testing soil and rock formations prior to erection of heavy structures.

The actual technique of drilling large-diameter holes has been described in many publications, and a selected bibliography of the subject is appended to this circular. However, the attention of the Bureau of Mines has been drawn to a current program of large-diameter calyx drilling being conducted by the Corps of Engineers at the Fort Randall dam site in South Dakota, for two principal reasons:

1. Core-handling methods deserve the attention of the mineral-mining industry where similar or modified practices may find application.

2. The Bureau of Mines has conducted investigations into all phases of utilization of low-grade manganese deposits immediately adjacent to the Fort Randall reservoir site. Any formation sampling, earth-moving operations, or developments directly or indirectly related to the deposits contributes information that might have an important effect upon possible future utilization of this reserve.

Accordingly, both the techniques employed in drilling and sampling and the results of sampling and stratigraphic studies conducted by the Corps of Engineers are considered significant subjects for study. The former is the principal topic of this circular.

## INTRODUCTION AND SUMMARY

As part of a general plan for control and economic utilization of the waters of the Missouri River Basin as well as development of its inherent power resources, the Corps of Engineers of the United States Army has under construction a rolled earth dam near the site of old Fort Randall in South Dakota. The dam is in Charles Mix and Gregory Counties on the Missouri River at a point about 922 miles above its mouth. It is approximately 125 air-line miles southeast of Pierre and 55 miles southwest of Mitchell, S. Dak.

The storage reservoir to be formed by the dam will extend upstream for 150 miles and, at maximum operating pool level, will cover an area of some 107,000 acres. It will have a storage capacity of 6.2 million acre feet.



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Initial power installations will consist of four 40,000-kw. generating units, but ultimate capacity will consist of eight units, or a total of 320,000 kilowatts. One of many important functions of the Fort Randall dam is to control floods, which in years past have caused extensive damage along the Missouri River and have contributed seriously to flood conditions in the Mississippi River below the point where the Missouri enters that stream.

In order that accurate data regarding subsurface conditions might be available for use in the structural planning of the dam, a large amount of churn and rotary drilling in the area immediately adjacent to the dam site was necessary and is still being carried on.

Drilling was begun in 1941, and 10 preliminary holes were put down that year. Subsequently, it was concluded that many more holes would be necessary to obtain desired information. As a result of the information obtained from churn and rotary drilling, it was deemed necessary to drill a number of large-diameter holes in order actually to observe undisturbed ground conditions below surface and to obtain large samples for physical testing.

Currently, such holes are being drilled only in areas at which the largest and heaviest structures are to be erected and where special construction consideration must be given to fault conditions and the presence of certain bentonite beds or bentonitic shales.

The following sections outline the drilling program and geology of the dam site, describe the drilling and sampling procedure in considerable detail, and list costs of contract items. The concluding pages sketch the application of large diameter coring technique; the last page comprises a selected bibliography of large-diameter drilling methods.

## ACKNOWLEDGMENTS

This study was compiled with the full cooperation of the Corps of Engineers and their contractor, the Pennsylvania Drilling Co. The assistance and cooperation of many individuals, both of the Army and of the contracting firm, were given freely. Special acknowledgment is made to the directing heads of the Engineer Corps both in the District Office in Omaha and at Area Headquarters at the dam site. George O. Evans, area engineer, John Trantina, chief of Engineering Division at the dam site, and L. B. Underwood, chief of Geology and Exploration Section of the area office, were particularly helpful, whereas F. C. Sturges, vice president of the Pennsylvania Drilling Co., and Vess Adams, local superintendent of the operation for the contractors, gave complete cooperation and furnished much information as to operating details.

The Bureau of Mines recognizes the importance of disseminating information on investigation of drilling methods for the benefit of the mining industry. The Mining Division, Lowell B. Moon, chief, conducts preliminary examinations, does the actual investigative work, and prepares the final report.



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## DRILLING PROGRAM AT FORT RANDALL

The drilling program, considered an important preconstruction function at Fort Randall, comprised three distinct phases:

1. Determination, by means of widely spaced rotary and churn-drill holes, of the general characteristics, thickness, and mode of occurrence of overburden; the elevation, character, and structure of the bedrock in areas where surface structures will be concentrated; and the general suitability for construction purposes of the materials excavated.

2. Subsequent drilling on closer coordinates to obtain samples of overburden and rock foundations; samples thus obtained to be tested in laboratories and closely examined for weathered areas where rock deterioration may have produced conditions of instability.

3. Further drilling of 36-inch calyx holes were soft rock, bentonitic material, zones of weathered shale, faults, shear zones, and like formation conditions make inspection-in-place desirable.

Three large-diameter calyx-drill holes have been drilled at this writing and are designated by the Corps of Engineers as Nos. 452 L-3, 159 L-4, and 281 L-5. All of the large-diameter holes were preceded by 6-inch diameter rotary-drill holes, which were carefully logged. The information so obtained was used in selecting the formations from which samples were to be taken in the large-diameter holes.

Hole 452, the initial 6-inch hole, and Hole 452 L-3, the subsequent 36-inch calyx hole, were drilled at a site to be occupied by the power house in order that foundation conditions might be known before final plans for the structure were drawn. At initial 6-inch hole 159, a second 6-inch hole, 159A, was drilled to confirm the findings of the original hole prior to the starting of the 36-inch hole L-4. Holes 159, 159A, and 159 L-4 were located to obtain information on underlying rock conditions that might affect a heavy retaining wall planned to separate the spillway proper from the power installations. Initial 6-inch hole 281 and the following 36-inch hole, 281 L-5, lie in the line of the gate structures of the spillway and were drilled so that the nature of the foundation under this construction would be known in advance of design acceptance. The author observed all operations connected with the drilling of hole 281 L-5 prior to the preparation of this circular.

Samples taken from the large-diameter holes were from depths selected by the Omaha District Office of the Corps of Engineers. Ordinarily, the samples were taken at elevations where bentonite seams were known to occur, as demonstrated from results of the preliminary small-hole drilling.

## GEOLOGY AND STRUCTURE IN THE FORT RANDALL AREA

Based on geological studies previously made in South Dakota and on detailed work performed in connection with planning and preconstruction



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operations, portions of the geological rock column of the general area immediately adjacent to the Fort Randall dam site, of importance to the structures to be erected there, have been determined as follows:

Geological section in Fort Randall area

| Elevation, feet | | Formation | Description |
|---|---|---|---|
| Top | Bottom | | |
| 1,490 | 1,380 | Glacial till | A mixture of clays, silts, and sands. |
| 1,380 | 1,320 | Pierre | Top 12 feet generally marl of the Gregory member. Below is Sharon Springs member, dark, firm, shale with bentonite seams plentiful near bottom. |
| 1,320 | 1,175 | Niobrara | This is the dominant formation of the area. The top 73 feet is the Smoky Hill member of gray, fossiliferous chalk. The bottom 72 feet is the Fort Hays member of mottled, gray chalk with a zone of thin bentonite seams near top. |
| 1,175 | 908 | Carlile | The top 80 feet is the Codell sandstone member of sandy shales to cemented sandstone; the middle 150 feet is made up of Blue Hill shale - a firm, dark-gray, "fat" material; the bottom 37 feet is the fossiliferous and calcareous Fairport chalky shale member. |
| 908 | 863 | Greenborn | A hard, banded, fossiliferous, gray limestone. |

The underlying Graneros formation of sandstones and shales, the Dakota formation of shale and sandstone, and the Sioux quartzite are not considered important to foundation requirements of the present construction program.

Details of the various geological formations have been adequately described and are only briefly summarized here.

The formations found in the region adjoining the Fort Randall dam are chiefly indurated and compacted sediments of Upper Cretaceous age ranging from the Greenhorn limestones upward through the Carlile shale, Niobrara chalk, and Pierre shale to the Fox Hill sandstone. The latter is well above the proposed pool level and of little importance to the dam structure itself.

The northeast abutment of the dam, where the large-diameter holes are located, lies in a promontory mantled by glacial till, which has a depth of approximately 100 feet. This represents a southwestern extension of the glaciers, which once covered many of the northern states and Canada. To the southwest, across the Missouri River, there is no effect of glaciation, as the river marks the general boundary in that direction.



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The Niobrara chalk is a compact chalk and chalky shale, generally gray to black in color, and, in the upper 20 feet, includes numerous small seams of bentonite. It is in general very uniform and, as stated in one of the Corps of Engineer's reports, "is considered to be the highest structural grade of the prevailing formations in the region" and suitable as a foundation rock for the dam.

Although the Pierre shale is one of the most widespread formations of South Dakota, it is almost absent in the immediate vicinity of the Fort Randall dam. Only a small portion of the formation was found in the area of the northeast abutment. Hole 281 L-5 was the only one of large diameter that encountered it. Several thin bentonite seams occur in the Pierre formation, but all of the formation will be removed in the excavations for the dam, thereby eliminating any difficulty from the bentonite.

Examination of the cores obtained from the L-5 hole discloses the presence of numerous joints throughout the rock, but they do not appear very prominent in a visual inspection of the walls of the hole, probably owing to an opening up after pressure is removed from them. In the earlier large-diameter holes, several examples of steeply dipping slickensided fractures appeared, but in hole L-5 no evidence of movement was to be seen, although numerous vertical joints were observed. The vertical fractures and horizontal bedding planes are seen in a section of core from hole L-5 pictured on figure 1.

## DRILLING PROCEDURE

Drilling large-diameter holes in the Fort Randall area presents two distinct problems - (1) penetrating the overburden and (2) drilling in bedrock. The area, made up of a heterogeneous mixture of clay, silt, sand, and gravel carrying numerous fragments of shale and chalk, constitutes the unconsolidated glacial till blanket of varying thickness. In color, it is mainly dark brown to dark gray, and the proportions of sand and clay vary without any apparent relationship between different types of material.

The material is somewhat compacted and requires considerable effort to loosen for excavation, although blasting is unnecessary. It stands in vertical walls without caving and, although somewhat damp when first exposed, dries out within a short time. Openings require support to forestall possible collapse.

The Niobrara chalk formation, which underlies the abutment areas, is considered the most favorable formation at required depth for a proper foundation for the structures and other appurtenances necessary in connection with building the dam. Several narrow seams of bentonite or bentonitic shale are found in the upper portion of the Niobrara formation, which require careful study and tests as to their possible action when heavily loaded and subjected to water action.

Although a generalized geologic column indicates the Pierre shale above the Niobrara chalk on the east side of the river in the immediate vicinity of the dam site, it is missing except in the small area surrounding hole



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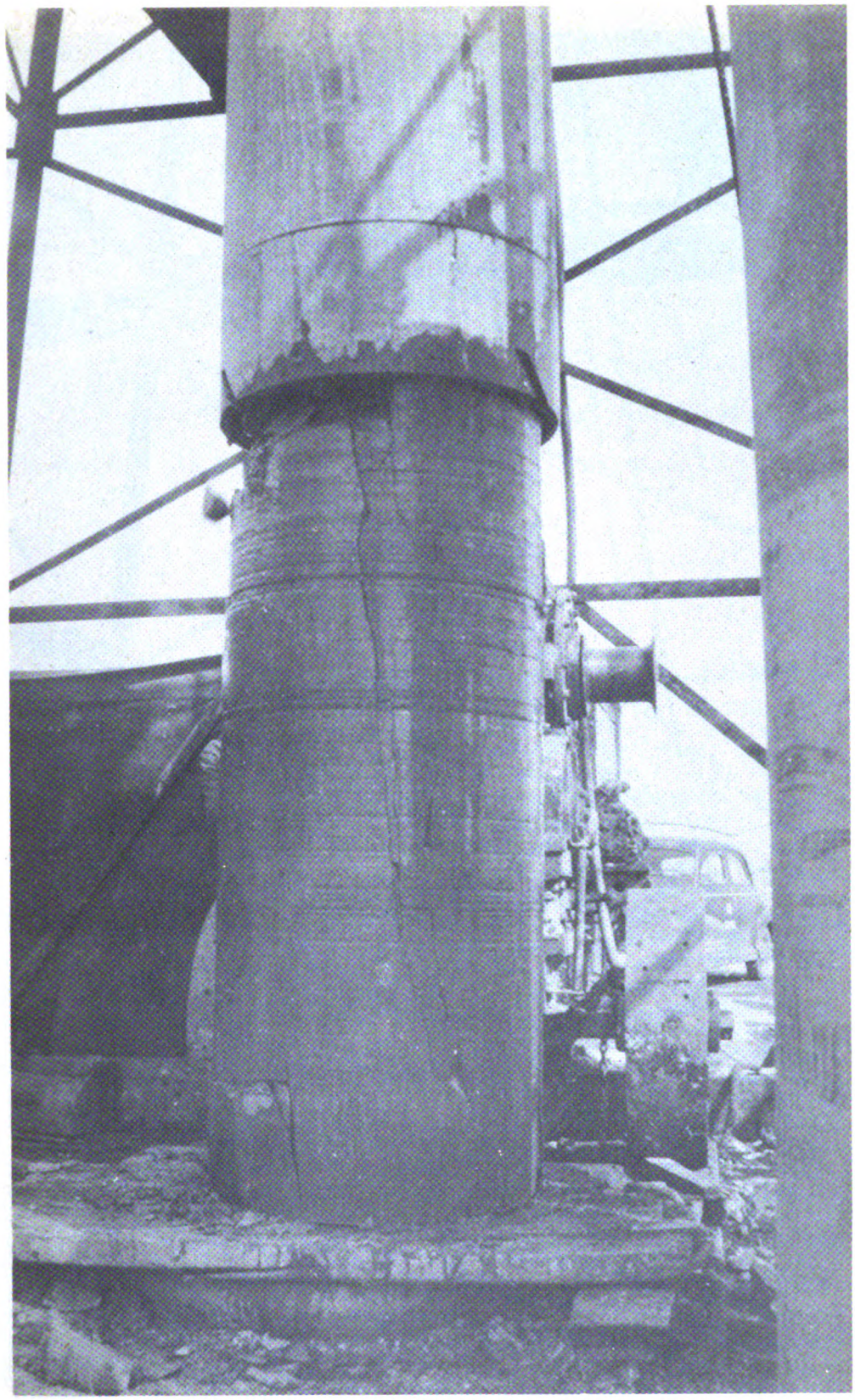

Figure 1. - Section of core from hole L-5, showing vertical fractures and horizontal bedding planes.

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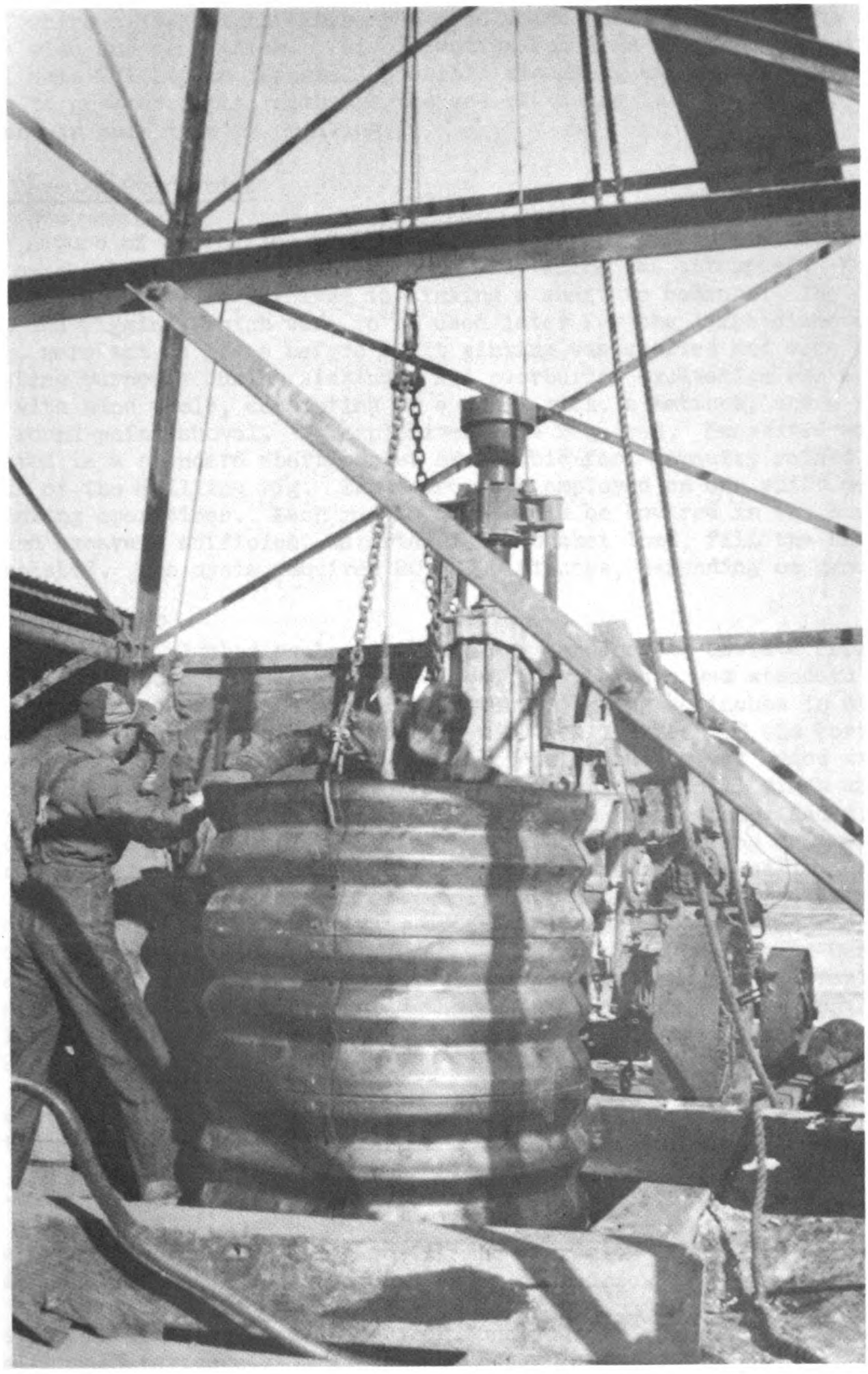

Figure 2. - Lowering 48-inch casing into hole L-5.

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281 L-5, where a 38-foot thickness was disclosed. Farther north, the Pierre shale is wide and very thick. This formation required the use of casing in drill hole 281 L-5 to forestall possible sloughing and interference with drilling to greater depth, although the use of casing is not customary or convenient in this type of drilling.

Sinking Through Overburden

The nature of overburden at the site of hole L-5 suggested that an excavation should be made to bedrock before drilling was attempted. No particular problems were involved in sinking a shaft to bedrock. The drill, derrick, and rigging, which were to be used later for the large-diameter drilling, were set in place before shaft sinking was started and were used for hoisting purposes during sinking. All overburden excavation was accomplished with hand tools, consisting of a small pick, a mattock, and a short-handled round-point shovel. No explosives were required. Excavated material was hoisted in a standard shaft bucket of 6 cubic-foot capacity raised with the winch of the drilling rig. Three men were employed on one shift during shaft-sinking operations. Each man in turn would be lowered in the bucket, loosen and excavate sufficient material for a bucket load, fill the bucket, and be hoisted. The cycle required 20 to 30 minutes, depending on ground conditions.

The shaft was plumbed each shift, and any tendency to deviate from vertical was overcome by trimming the sides. Casing used was standard 12-gage, corrugated-steel, sectionalized, tunnel tubing 48 inches in diameter. Specifications required casing to be kept within 4-1/2 feet of the bottom of the excavation. For the first 16-1/2 feet of hole, casing was added as required by raising the entire string of casing with the drill winch and attaching a new length to the bottom. Below 16-1/2 feet, casing additions were made at the collar, and the string was lowered by removing and replacing in the new position the supporting bolts on permanent surface sills. With a short footage of casing in the hole, only two bolts through the surface sills were needed to support it; but, after a depth of 60 feet was reached, cross sills were installed at the surface, and two additional bolts were added for this support. Even with this number of supports, considerable care was required to prevent dropping the casing or tearing the holes for port bolts. The casing and method used for lowering it are shown on figure 2.

A ventilating fan powered by an air-cooled gasoline motor was used for ventilation at the shaft bottom. Air was transmitted through a 10-inch ventube, which was withdrawn from the hole each time casing was installed. A 1,500-watt portable power plant supplied power for lighting the shaft.

The daily record of progress during the operation of sinking through overburden and setting the overburden casing in bedrock is shown on table 1.

A study of time involved in various functions of sinking in overburden during a representative period is summarized in table 2.



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TABLE 1. - Progress record - sinking in overburden

| Date, 1948 [1] | Sinking | | | | | | Casing | | |
|---|---|---|---|---|---|---|---|---|---|
| | Depth, beginning of shift | | Depth, end of shift | | Advance, | | Sections installed | Depth, end of shift [2] | |
| | Feet | Inches | Feet | Inches | Feet | Inches | | Feet | Inches |
| Jan. 5 | 5 | 0 | 11 | 6 | 6 | 6 | 4 | 6 | 0 |
| 6 | 11 | 6 | 16 | 0 | 4 | 6 | - | 6 | 0 |
| 7 | 16 | 0 | 19 | 0 | 3 | 0 | 7 | 16 | 6 |
| 8 | 19 | 0 | 23 | 0 | 4 | 0 | 2 | 19 | 6 |
| 9 | 23 | 0 | 26 | 0 | 3 | 0 | 2 | 22 | 6 |
| 10 | 26 | 0 | 29 | 6 | 3 | 6 | 3 | 27 | 0 |
| 12 | 29 | 6 | 32 | 6 | 3 | 0 | 2 | 30 | 0 |
| 13 | 32 | 6 | 35 | 6 | 3 | 0 | - | 30 | 0 |
| 14 | 35 | 6 | 38 | 6 | 3 | 0 | 2 | 33 | 0 |
| 15 | | | | | | | | | |
| 16 | 38 | 6 | 40 | 0 | 1 | 6 | 2 | 36 | 0 |
| 17 | 40 | 0 | 42 | 6 | 2 | 6 | 2 | 39 | 0 |
| 19 | 42 | 6 | 46 | 0 | 3 | 6 | 2 | 42 | 0 |
| 20 | 46 | 0 | 49 | 6 | 3 | 6 | 2 | 45 | 0 |
| 21 | 49 | 6 | 54 | 0 | 4 | 6 | 2 | 48 | 0 |
| 22 | 54 | 0 | 56 | 6 | 2 | 6 | 2 | 51 | 0 |
| 23 | | | | | | | | | |
| 24 | | | | | | | | | |
| 26 | 56 | 6 | 58 | 6 | 2 | 0 | 2 | 54 | 0 |
| 27 | 58 | 6 | 60 | 6 | 2 | 0 | 2 | 57 | 0 |
| 28 | 60 | 6 | 62 | 6 | 2 | 0 | 2 | 60 | 0 |
| 29 | 62 | 6 | 65 | 6 | 3 | 0 | - | 60 | 0 |
| 30 | 65 | 6 | 68 | 0 | 2 | 6 | 2 | 63 | 0 |
| 31 | 68 | 0 | 70 | 0 | 2 | 0 | 2 | 66 | 0 |
| Feb. 2 | 70 | 0 | 70 | 6 | 0 | 6 | 3 | 70 | 6 |
| 22 days | | | | | 65 | 6 | 47 | 70 | 6 |
| Average per day | | | | | 2.98 | | | 3.20 | |

1/ No work on January 15, 23, and 24 on account of low temperatures and blizzard.

2/ Bedrock at 70 feet, 4 inches; + casing set at 70 feet, 6 inches.



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TABLE 2. - Time studies of sinking in overburden

| Date Jan. | Excavation | | | Casing | | | Start & Close | | | Lunch | | | Delays | | | Total | | Depth, Feet | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hour | Minute | Percent | Hour | Minute | Percent | Hour | Minute | Percent | Hour | Minute | Percent | Hour | Minute | Percent | Hour | Minute | From | To |
| 9 | 6 | 37 | 69.7 | 0 | 55 | 9.7 | 1 | 07 | 11.6 | 0 | 50 | 8.7 | 0 | 1 | .2 | 9 | 30 | 23.0 | 26.0 |
| 14 | 5 | 52 | 61.6 | 0 | 37 | 6.3 | 1 | 56 | 20.3 | 0 | 55 | 9.7 | 0 | 10 | 2.1 | 9 | 30 | 35.5 | 38.5 |
| 16 | 5 | 36 | 65.9 | 0 | 30 | 5.9 | 1 | 28 | 17.3 | 0 | 49 | 9.6 | 0 | 7 | 1.4 | 8 | 30 | 38.5 | 40.0 |
| 22 | 6 | 17 | 66.1 | 0 | 55 | 9.7 | 1 | 28 | 15.5 | 0 | 43 | 7.6 | 0 | 7 | 1.3 | 9 | 30 | 54.0 | 56.5 |
| 26 | 4 | 19 | 54.0 | 1/1 | 20 | 16.6 | 1 | 20 | 16.6 | 0 | 49 | 10.3 | 0 | 12 | 2.5 | 8 | 0 | 56.5 | 58.5 |
| 28 | 5 | 42 | 60.0 | 0 | 45 | 7.9 | 1 | 43 | 18.1 | 0 | 20 | 3.5 | 2/1 | 0 | 10.5 | 9 | 30 | 60.5 | 62.5 |
| 29 | 7 | 10 | 75.4 | - | - | - | 0 | 40 | 7.0 | 0 | 45 | 7.9 | 3/0 | 55 | 9.7 | 9 | 30 | 62.5 | 65.5 |
| 30 | 6 | 44 | 70.9 | 0 | 38 | 6.6 | 0 | 51 | 8.9 | 0 | 46 | 8.1 | 4/0 | 31 | 5.5 | 9 | 30 | 65.5 | 68.0 |
| Average | 6 | 2 | 65.6 | 0 | 42 | 7.6 | 1 | 19 | 14.3 | 0 | 46 | 8.3 | 0 | 23 | 4.2 | 9 | 12 | | |

1/ Setting sills - 35 minutes.
2/ Sampling - 1 hour.
3/ Plumbing shaft and correcting.
4/ Testing for gas - none present.



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## Safety Measures During Sinking Operations in Overburden

Previous experience in the sinking of calyx drill holes in the Fort Randall area has shown that small accumulations of gas are to be found at places in the glacial till overburden. In order that the men working in the shaft from which the calyx hole L-5 was to be drilled might not be exposed to unnecessary risks, and as a precaution against any gas, certain safety measures were put into effect at the start of sinking operations and were maintained at all times.

When working in the shaft, the man wore the usual approved safety helmet and a safety belt or harness similar to that developed for use of paratroopers. A half-inch hemp rope was fastened to the harness and passed over a sheave at the top of the derrick and thence to the collar of the shaft, where it was easily accessible to other men on the shift. The rope could be passed rapidly around the "nigger-head" drum of the hoisting engine if it became necessary to remove the man from the shaft at any time.

An auxiliary 5-foot piece of steel cable was permanently attached to the hoisting cable in a position that permitted the lower end to be easily snapped to the man's harness while he was riding the bucket either up or down. This was done to prevent his falling from the bucket if overcome by gas. The equipment is shown in figure 3.

To indicate the presence of any gas, the air in the shaft was tested at the beginning of each shift and before the first man entered the bore. A safety lamp was used for testing by lowering the lamp to the shaft bottom and observing its action from the surface. The lamp was also kept at the bottom of the shaft during the entire time men were at work.

The ventilating fan was started at the beginning of each shift about 10 minutes before men entered the shaft and when work was resumed after casing was installed. If, during the noon hour or at any other time, the fan was shut off for any reason, it was always started well before the time men returned to work in the bottom of the shaft.

Safety measures contemplated, first, the detection of gas if encountered; second, the prevention of a man's fall from the bucket if overcome by gas or any other cause of disability; and third, his removal to the surface, if unconscious, without the necessity for another man to enter the shaft.

Fresh-air helmet equipment, masks, hoses, and blower were kept in storage at the collar of the shaft for use in case of emergency.

## Drilling in Bedrock

Bedrock was encountered in the shaft portion of hole L-5 at a depth of 70 feet, and surface casing was cemented in place at 71 feet. The hole was then deepened to 190 feet with a heavy-duty, hydraulic-feed, core drill powered by a 54-high powered 4 cylinder, gasoline engine. The bit used was 36 inches in outside diameter and produced a core with a diameter of 32



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inches. Because the weight of the drill rods, core barrel, and bit was sufficient to supply the necessary pressure for drilling, the hydraulic-feed mechanism of the drill was not required.

Drill rods consisted of 15-foot lengths of 4-inch, extra-heavy, black pipe, to each end of which was welded a flange drilled with eight bolt holes. A short 7-foot rod was on hand for use when advance was insufficient to permit the addition of a full 15-foot section. After release from the drill, the string of rods and tools was held in the hole by placing a shoe on the heavy timber covering of the hole. The shoe could be fitted around the rod and under a coupling flange. A bail of 3/4-inch steel could be quickly coupled to the rod flanges to permit raising or lowering drill rods. When pulling from deep holes, rods were usually disconnected in 30-foot lengths and stood out of the way in the corner of the derrick in a manner similar, but on a smaller scale, to the practice employed in drilling oil wells.

Rotary motion was imparted to the rods through a square kelly-bar and coupling in the conventional manner. Derrick and drill set-up is shown in figure 4.

The hole was kept full of water circulated through the drill rods, the core barrel, and the hole. This circulation brought the bulk of cuttings to the surface where they were settled out of the water in a sump dug nearby. Heavier cuttings were caught in the calyx at the top of the core barrel from where they were removed when the barrel was brought to the surface.

Both a single-tube core barrel with saw toothed bit and a double-tube barrel with a bit using shot for the cutting medium were used in drilling hole L-5.

The single-tube barrel was a hollow shell of 1/2-inch steel plate 11 feet long and 36 inches in diameter. To the lower end was attached, by riveting and welding, a 1-inch steel bit having 12 hard-surfaced teeth 1 inch in length around the circumference. A horizontal plate was welded inside the shell 12 inches below the upper end, which formed the "calyx" of the drill and caught a large portion of the cuttings too heavy for lifting to the surface by the circulating water. Over-all length of the single-tube barrel and bit was 12-1/2 feet.

Core cut by the single-tube barrel and saw-toothed bit was removed from the hole either by the independent core puller or by using the double-tube barrel as a core puller. Both of the pulling tools gripped the core by reversal of the rotation of the tool string, which, through the action of a left-hand thread at the top of the puller, forced the teeth of the puller into the core and thus gave a grip for lifting it to the surface.

The double-tube barrel used in this drilling was developed by the drilling contractor. The outside diameter of the tool was 36 inches, and the over-all length was 16-1/2 feet. The inside shell was of 1/2-inch steel plate 10 feet long and was attached to a left-hand thread on the rods, thus permitting the barrel to be moved up or down as required and, by means



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of a tapered piece between the shells, to be forced into close contact with the core. This gave a grip similar to that of the core puller and allowed the core to be removed from the hole.

The advantage of using the double-tube barrel with core lifter was that the core was completely enclosed and gripped near the bottom when pulling, which to a certain extent precluded breakage and loss of the core. The independent puller gripped the core about 18 inches from the upper end, and where a core was broken several pulls would be necessary to extract all of it from the hole.

The release and removal of core from the barrel were performed on a platform directly above the hole. The core was rested directly on the platform or on a block placed underneath if the break took place some distance up in the barrel. The grip was released by reversing the threads of the top of the lifter assembly; and, with the core resting on the platform, the barrel was raised until the entire length of core stood free. Where the core was fractured, it was not uncommon to have it fall from the barrel before it was freed from the lifters.

After the core had been freed from the core barrel, measured, and inspected, it was removed from over the hole, and the drilling tools were again lowered preparatory to resumption of drilling.

Figure 5 shows the double-tube barrel resting on the platform over the hole preparatory to loosening lifters. Figures 1, 6, and 7 show typical sections of long core after removal from the barrel. Sections of broken core are shown in the foreground on figure 7.

The drill hole penetrated Gregory marl and Pierre shale from 70 feet to 114.5 feet. General conditions in this part of the hole were such as to require casing, and, therefore, this section was reamed to a diameter of 44 inches, and 46 linear feet of 43-inch diameter corrugated tubing was installed.

The reaming tool consisted of an iron plate 36 inches long, 6 inches wide, and 1/2 inch thick, to the ends of which were fastened two heavier short-angle irons set with two hard-surfaced cutting teeth. The angle irons were pivoted but, during cutting, rested against lugs on the long bar, thus being held against the rock being cut. When the reaming cut was completed, a reversal of the tool string swung the cutters towards the center of the hole and permitted them to be pulled out.

Two reaming cuts were made in hole L-5 to obtain a hole of the desired size for casing. The first of these cuts was made at a speed of 45 r.p.m., whereas the second cut was run at 32 r.p.m. Because a considerable amount of cuttings from the second cut dropped to the bottom of the hole, thus producing a thick sludge or slurry through which it was difficult to force the core barrel, bailing was necessary. This was done with either an 18-inch by 8-foot flap-valve bailer or piston type sand pump.



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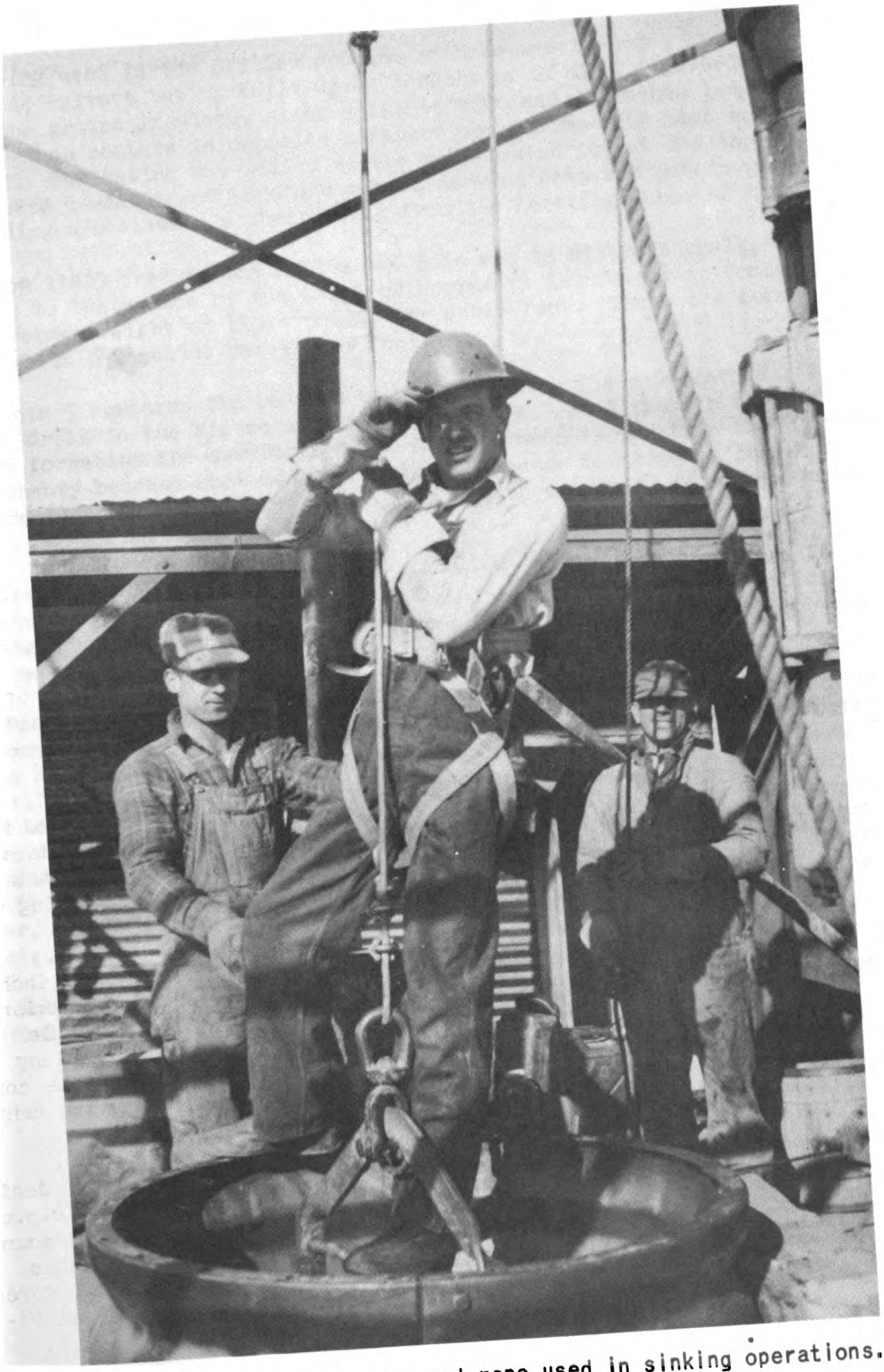

Figure 3. - Safety harness and rope used in sinking operations.

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Casing used in the drilled section of hole was 12-gage, standard, corrugated, culvert tubing built up to lengths of 20 feet. In order to observe the ground in place, slots 4 inches wide and 12 inches long were cut on 16-inch centers in opposite sides of the casing with each row staggered. The casing was sealed to the rock behind it, at the top and bottom, with a mixture of sand and cement carried down and put in place by a man riding a boatswain's chair swung from the hoisting cable of the drill.

From 114.5 feet to the bottom the hole was in Niobrara chalk, which, according to tests made by the Corps of Engineers laboratory in Omaha, has an average weight of 115.4 pounds per cubic foot. Thus, the core weighed about 640 pounds per linear foot.

Table 3 compares the results of drilling with the saw-toothed bit and the shot drill in the Niobrara chalk. It will be noted that in the soft Niobrara formation the saw-toothed bit drilled much faster than the shot bit, probably because shot had a tendency to become imbedded in the soft rock, precluding the breakage and rolling action essential to satisfactory cutting.

Although the difference in the rate of drilling advance between the double-tube barrel and the single-tube saw-tooth combination was noticeable, the advantage of the toothed bit was offset to a considerable degree by the necessity of changing tools to pull the core.

Breaking core preliminary to removing it from the hole required varying amounts of time and was dependent on the strength of formations drilled. When in hard formations, the procedure involved placing large jacks under the drill chuck and exerting a lifting strain through the kelly bar by means of the hoisting cable. Such strain was maintained for as long as 12 hours or more in extreme cases. In the Niobrara chalk formation, most pulls were short and the core was withdrawn without special breaking, although several times it was necessary to place a strain on the cable for about 20 minutes. However, in the Pierre shale some breaks required as much as 18 hours to complete.

Table 4 shows the time distribution of the operation from the start of actual drilling to a depth of 175 feet, 9 inches.



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TABLE 3. - Comparison of single-tube core barrel with saw-tooth bit and double-tube core barrel using shot bit

| Barrel | Bit | Advance, feet | | | Time | | | | Feet per hour | | Method |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Interval | | Drilling only[1] | | Including breaking core and pulling | | | | |
| | | Total | From- | To- | Hours | Minutes | Hours | Minutes | Drilling only | Including breaking core and pulling | |
| Double | Shot | 24.0 | 113.25 | 137.25 | 26 | 56 | 30 | 57 | 0.89 | 0.78 | Drilled and pulled by double barrel. |
| Single | Toothed | 15.0 | 137.25 | 152.25 | 3 | 40 | 5 | 33 | 4.09 | 2.70 | Drilled and pulled by single barrel. |
| | Toothed | 23.5 | 152.25 | 175.75 | 5 | 37 | 13 | 30 | 4.18 | 1.74 | Drilled single, pulled by double barrel. |
| | Toothed | 38.5 | | | 9 | 17 | 19 | 3 | 4.15 | 2.04 | |

1/ Measured from start of rotation of bit, even though not on bottom but going through sludge to get to bottom.



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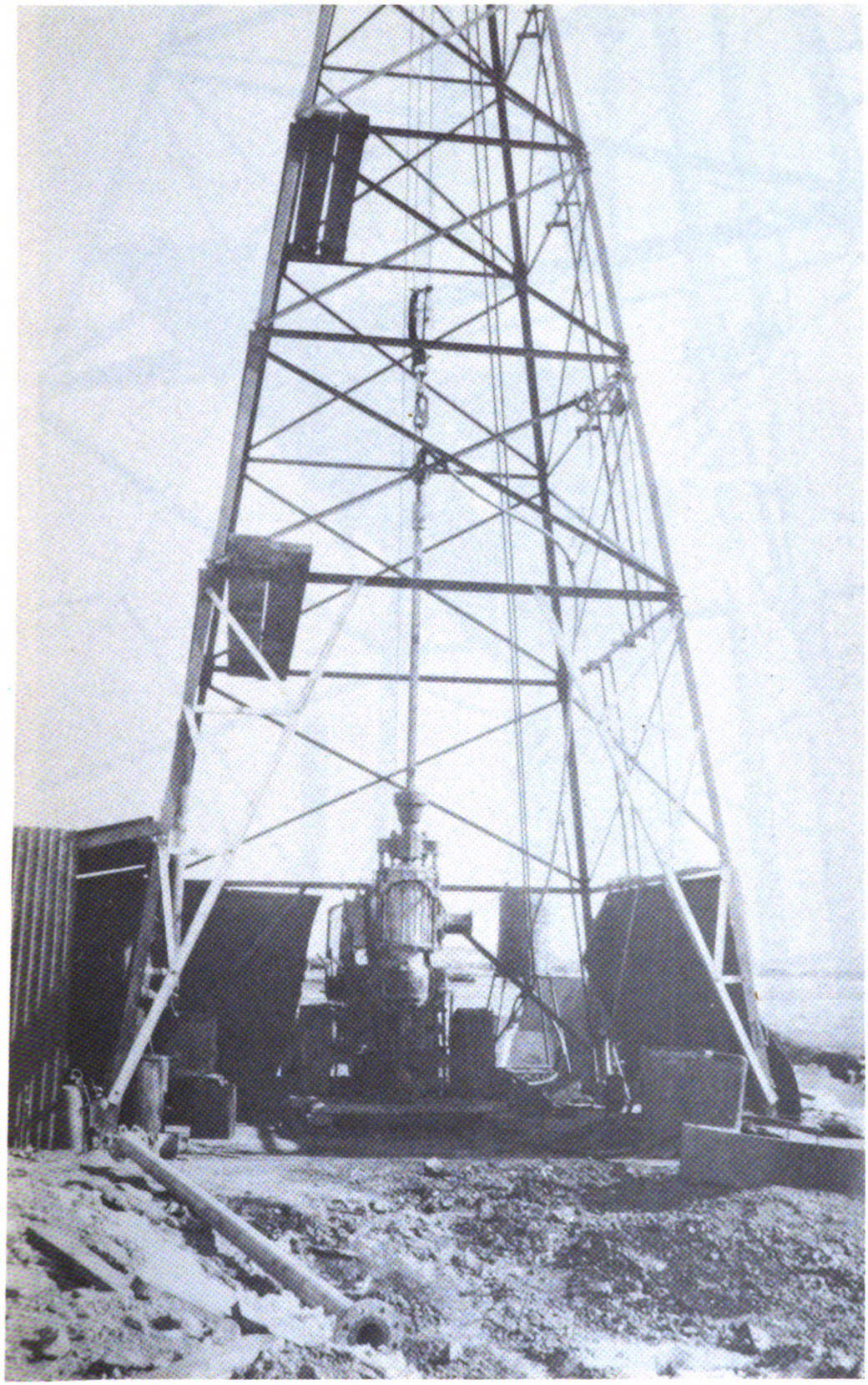

Figure 4. - Derrick and drill at hole L-5.

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Figure 5. - Core barrel resting on platform above hole L-5 preparatory to loosening grip of lifters on core.

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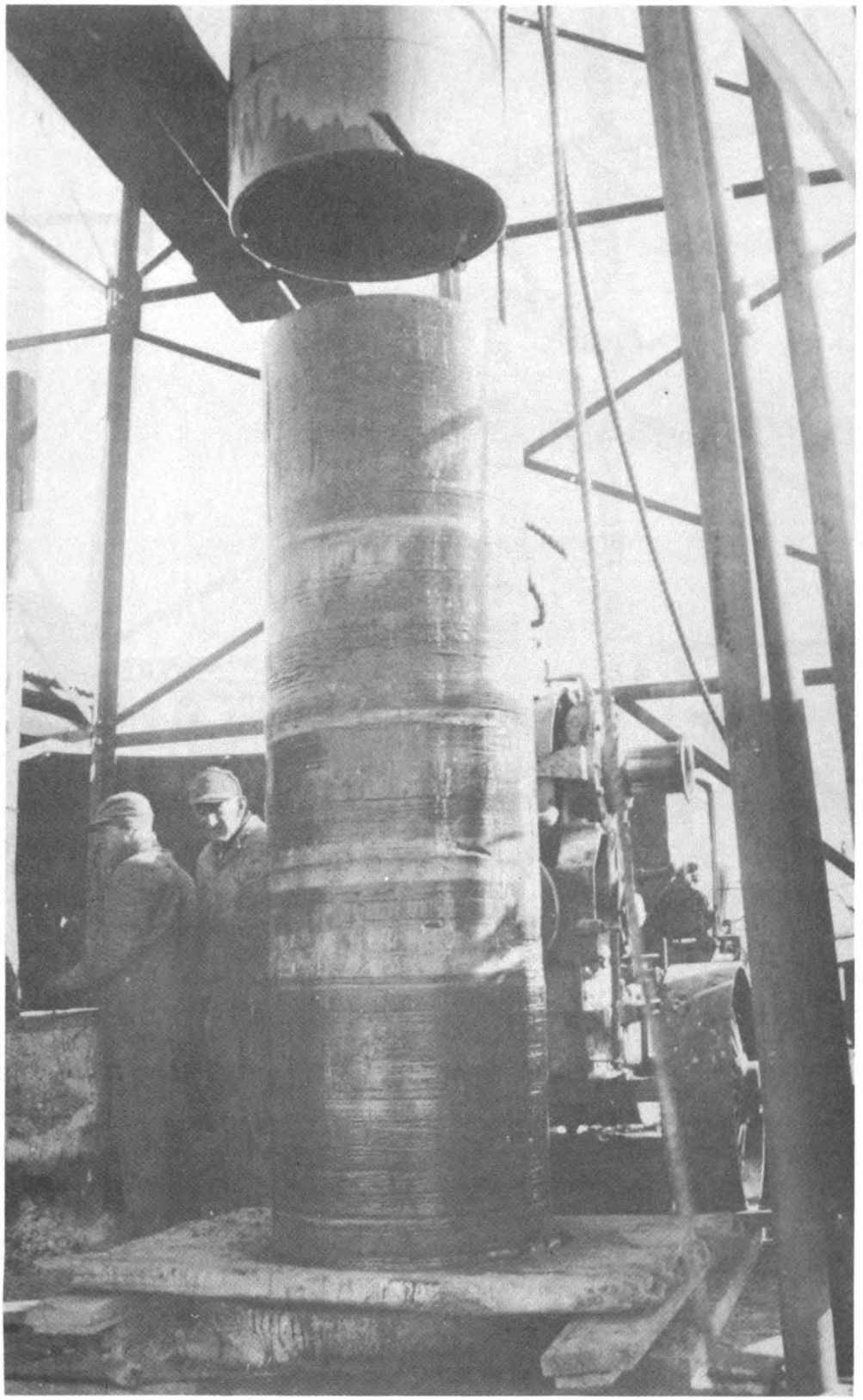

Figure 6. - Section of core immediately after removal from core barrel.

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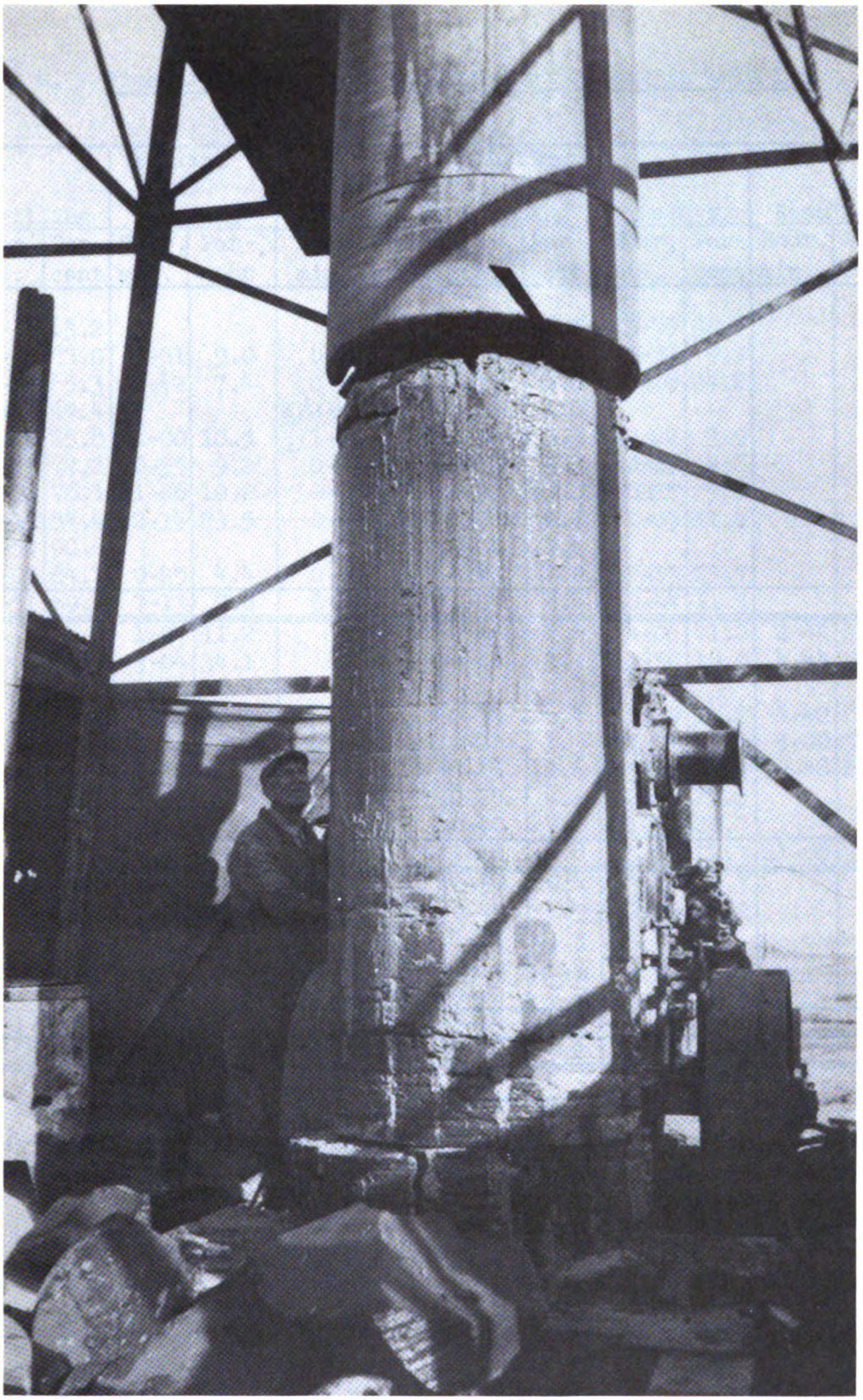

Figure 7. - Section of core from hole L-5; sections of broken core in the foreground.

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TABLE 4. - Time distribution of drilling in bedrock in hole L-5

| Date, 1948 | Drilling | | Pulling and lowering | | Breaking core | | Starting and stopping | | Delays | | Reaming | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hour, min. | Per-cent | Hour, min. | Per-cent | Hour, min. | Per-cent | Hour, min. | Per-cent | Hour, min. | Per-cent | Hour, min. | Per-cent |
| Feb. | | | | | | | | | | | | |
| 13 | 6- 0 | 63.2 | | | | | 0-35 | 6.1 | 2-55 | 30.7 | | |
| 16 | 6-10 | 65.0 | 0-51 | 9.0 | 0-16 | 2.8 | 1-20 | 14.0 | 0-53 | 9.3 | | |
| 17 | 6-12 | 65.3 | 0-42 | 7.4 | 0-08 | 1.4 | 0-10 | 1.8 | 2-18 | 24.2 | | |
| 18 | 6-35 | 69.4 | | | 2/2-45 | 28.9 | 0-10 | 1.8 | | | | |
| 19 | 6-15 | 65.8 | 1-00 | 10.5 | 3/1-23 | 14.6 | 0-30 | 5.3 | 0-22 | 3.9 | | |
| 20 | 7-43 | 77.2 | 0-55 | 9.2 | 0-35 | 5.8 | 0-18 | 3.0 | 0-29 | 4.8 | | |
| 21 | 6-51 | 76.1 | 1-06 | 12.2 | 0-05 | 0.9 | 0-31 | 5.8 | 0-27 | 5.0 | | |
| 23 | 5-10 | 54.4 | 2-14 | 23.5 | 0-06 | 1.1 | 0-55 | 9.7 | 1-05 | 11.4 | | |
| 24 | 8-50 | 90.6 | | | | | 0-55 | 9.4 | | | | |
| 25 | 6-05 | 64.1 | 0-25 | 4.4 | 0-05 | 0.9 | 0-40 | 7.0 | 2-15 | 23.7 | | |
| Total | 65-51 | 69.1 | 7-13 | 7.6 | 5-23 | 5.6 | 6-04 | 6.4 | 10-44 | 11.3 | | |
| 26 | | | 1-07 | 11.2 | | | 0-45 | 7.5 | 4-06 | 41.0 | 2-42 | 27.0 |
| 27 | | | 3-04 | 34.1 | | | 0-18 | 3.3 | 0-54 | 10.0 | 4-44 | 52.6 |
| March | | | | | | | | | | | | |
| 1 | | | 1-51 | 18.0 | | | 0-33 | 5.4 | 1-09 | 11.2 | 6-42 | 65.4 |
| 2 | | | 2-42 | 28.4 | | | 0-20 | 3.5 | 1-28 | 15.5 | 5-00 | 52.6 |
| 3 | | | 1-12 | 12.6 | | | 0-15 | 2.6 | 3-15 | 34.2 | 2-48 | 29.5 |
| 4 | | | | | | | 0-25 | 4.2 | 2-35 | 25.2 | | |
| 5 | | | | | | | 0-40 | 7.0 | 1-58 | 20.7 | | |
| Total | | | 9-56 | 14.6 | | | 3-16 | 4.8 | 15-25 | 22.7 | 21-56 | 32.3 |
| 8 | 3-40 | 37.7 | 1-53 | 19.2 | | | 0-55 | 9.4 | 3-17 | 33.7 | | |
| 9 | 3-37 | 38.1 | 2-51 | 30.0 | 0-05 | 0.9 | 0-45 | 7.9 | 2-12 | 23.2 | | |
| 10 | | | 0-15 | 16.7 | | | 1-15 | 83.3 | | | | |
| 11 | 2-00 | 27.0 | 2-31 | 34.0 | 0-18 | 4.0 | 1-10 | 15.7 | 1-26 | 19.3 | | |
| 12 | | | 1-48 | 24.6 | 0-20 | 4.5 | 0-22 | 5.0 | 1-37 | 22.2 | | |
| Total | 9-17 | 27.3 | 9-03 | 26.7 | 0-43 | 2.1 | 3-12 | 9.4 | 8-32 | 25.1 | | |
| Total | 75-08 | 58.1 | 16-16 | 12.6 | 6-06 | 4.7 | 9-16 | 7.2 | 19-16 | 14.9 | | |

1/ "G", Gregory marl; "P", Pierre shale; "N", Niobrara chalk.
2/ Break at 8:53 a.m., 2/19/48 - 18 hr. 33 min.
3/ Break at 8:05 a.m., 2/20/48 - 15 hr. 35 min.



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TABLE 4. - Time distribution of drilling in bedrock in hole L-5 (Cont'd)

| Date 1948 | Casing and cementing | | Bailing and sampling | | Total shift | Advance | Core recovered | Drilling advance per hour | Formation 1/ |
|---|---|---|---|---|---|---|---|---|---|
| | Hour, min. | Per-cent | Hour, min. | Per-cent | Hour, min. | feet inches | feet inches | feet | |
| Feb. | | | | | | | | | |
| 13 | | | | | 9-30 | 5- 0 | | 0.83 | G |
| 16 | | | | | 9-30 | 6- 0 | 9- 9 | .97 | P |
| 17 | | | | | 9-30 | 7- 9 | 7- 8 | 1.25 | P |
| 18 | | | | | 9-30 | 9- 0 | | 1.37 | P |
| 19 | | | | | 9-30 | 7- 0 | 7- 0 | 1.12 | P |
| 20 | | | | | 10-00 | 7- 6 | 9- 6 | 0.99 | P |
| 21 | | | | | 9-00 | 8- 8 | 9- 4 | 1.27 | N |
| 23 | | | | | 9-30 | 6-10 | 14- 8 | 1.32 | N |
| 24 | | | | | 9-45 | 6- 0 | | 0.68 | N |
| 25 | | | | | 9-30 | 2- 6 | 6- 8 | 0.41 | N |
| Total | | | | | 95-15 | 66- 3 | 64- 7 | 1.01 | |
| 26 | | | 1-20 | 13.3 | 10-00 | 17- 3 | | | |
| 27 | | | | | 9-00 | 33- 9 | | | |
| March | | | | | | | | | |
| 1 | | | | | 10-15 | 18- 3 | | | |
| 2 | | | | | 9-30 | 13- 6 | | | |
| 3 | | | 2-00 | 21.1 | 9-30 | 6- 3 | | | |
| 4 | 5-55 | 57.7 | 1-20 | 13.0 | 10-15 | | | | |
| 5 | 6-52 | 72.3 | | | 9-30 | | | | |
| Total | 12-47 | 18.8 | 4-40 | 6.9 | 68-00 | | | | N |
| 8 | | | | | 9-45 | 15- 0 | 14-10 | 4.09 | |
| 9 | | | | | 9-30 | 15- 6 | 7- 9 | 4.28 | |
| 10 | | | | | 1-30 | | | | |
| 11 | | | | | 7-25 | 8- 0 | 8- 6 | 4.00 | |
| 12 | | | 3-13 | 43.8 | 7-20 | | 8- 8 | | |
| Total | | | 3-13 | 9.5 | 34-00 | 38- 6 | 39- 9 | 4.15 | N |
| Total | | | 3-13 | 2.5 | 129-15 | 104- 9 | 104- 4 | 1.39 | |

The cycle of operations is broken down into seven phases, as follows:

1. Drilling. Actual ground cutting.

2. Breaking core so as to bring it out of the hole.

3. Raising and lowering tools and core.

4. Starting and stopping. Time necessary to prepare for work in the morning and to leave the rig in condition for the night.

5. Casing and cementing, bailing, and sampling.

6. Reaming. This replaced drilling during enlargements of the diameter of the hole between 71 and 115 feet.

7. Delays. In this operation is included lunch time, work on motor and engines, changing cables on the drill, bringing tools and other equipment to the rig, removal of core from the lifting barrel, etc.



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In the above breakdown of operations, "drilling" represents actual ground cutting only and was measured from the moment the bit began to rotate to the time when strain was put on the tools to break the core after the cut had been completed full length. "Breaking core" represents the time required to break off the core cut by the drilling action preparatory to lifting it to the surface. "Raising and lowering tools and core" represents the time required to remove the tools from the hole and to lower them again after removing the core from the barrel. "Starting and stopping" includes the time consumed by work preparatory to commencing and stopping operations. "Casing and cementing," "bailing," and "sampling" are operations in effect for short periods and in general were not recurring. "Reaming" replaced the drilling item while enlarging the hole preparatory to casing. "Delays" include the miscellaneous losses of time due to unforeseeable causes, such as the time consumed in removing the core from the barrel, changing tools, changing cables for various operations, and machinery breakdowns.

## SAMPLING PROCEDURE

Although the large-diameter holes at Fort Randall dam site were drilled primarily to observe and sample the bedrock, it was deemed advisable, also, to obtain samples of undisturbed overburden for density moisture-content determinations.

The samples of overburden were taken at approximately 15-foot depth intervals. At these points, a section of the bottom of the excavation about 1 foot in diameter and 1 foot in height was left in place. This projection was trimmed by a sampler, so that a sample-can could be placed over it without disturbing the formation and then be cut off below the can.

This procedure gave a final undisturbed section of overburden material about 6 inches in diameter and 10 inches in height. Tests were made on this cylinder for density and moisture content, determinations which were considered the only tests to which the sample was amenable.

Samples from selected places in the bedrock were taken to determine the reaction of the formations to superimposed weight and the effect of bentonite seams upon such reactions. These samples were cylinders of core containing a bentonite seam or seams, on each side of which was undisturbed bedrock.

In hole L-5, four samples were desired, but only one, from the lowest point, was obtained, owing to the fact that at the upper locations the formations were so fractured close to the bentonite seams that the core would not hold together while being handled. A method of preparing samples of core to assure their arrival at the testing laboratory in as nearly in situ position as possible was developed in earlier drilling and was used here with some modification.

After the core enclosing an important bentonite seam was brought to the surface, it was closely inspected and marked for cutting at points about 9 inches above and below the bentonite seam. The core was cut at these points by means of a coarse-tooth crosscut hand saw. The undesired portion of core above the top cut was then lifted off, and the lower cut was made. The sample was carefully lifted and placed on a special wooden tray. It was then washed with one coat of liquid wax, wrapped in cheesecloth, and



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again waxed to prevent slacking of the bentonite by any action of air or moisture. Vertical holes 1 inch in diameter were then drilled through the sample at regular intervals by means of an electric drill. Wooden dowels were then cemented in the holes to serve as keys for holding the sections of the formation in place. Prior to use, the wooden dowels had been thoroughly water-soaked to insure against swelling after they were in the core.

Figures 8 and 9 show the method of drilling dowel holes and the core section with the dowel pins in place. Dowel holes were spotted by trisecting the area of the core sample top forming three radii 120 degrees apart. Holes were drilled on centers 2-1/2 inches on each side of each radius at points 1 foot from the center of the sample.

After the dowel pins had set, the sample was cut into three equal wedge-shape segments, each containing two dowel pins. Thereafter, each segment was wrapped and waxed preparatory to shipment to the laboratory for testing.

## COSTS

Contract items under which the work was done are as follows:

| | | |
|---|---|---|
| 1. | Mobilization and demobilization ...lump sum | $ 725.00 |
| 2. | Exploratory hole in overburden ....per foot | 75.00 |
| 3. | Exploratory hole in bedrock .....per foot | 70.00 |
| 4. | Reaming and casing in bedrock .....per foot | 35.00 |
| 5. | Doweled samples .....each | 100.00 |

The wage scale in effect when the hole was drilled was:

Driller (foreman)..$1.35 per hour plus monthly bonus.
Drill helpers ..... 1.00 per hour

Time and a half was paid for hours in excess of 40 per week. Work was carried on 9 hours per day, 6 days per week.

## APPLICATION OF LARGE-DIAMETER CORING TECHNIQUES

Various methods used for drilling large-diameter holes have in general (1) followed ordinary core-drill techniques, (2) utilized modifications of the procedures developed in petroleum drilling, or (3) developed along somewhat novel lines with the design of specialized equipment for use in these holes.

In general, the use of a rotary rig such as used in the oil fields does not produce a recoverable core. Rotary equipment has been used for drilling pilot holes, such as a 12-inch diameter hole, and successive reamings have enlarged diameters to as much as 84 inches. Such holes have been lined and used successfully as mine shafts. With regular oil-field rotary methods the hole is kept full of a carefully weighted drilling mud to prevent caving



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of the walls or blow-outs. Circulation is maintained through the string of rods from the rotary table on surface to the bit at the bottom of the hole to remove cuttings.

In the mid thirties, a good deal of study and considerable money were spent in the development of special equipment for drilling large-diameter holes. The principal effort was in Grass Valley, Calif., and the equipment developed there has been used successfully in several places in the United States, holes of 60 and 66 inches diameters being completed to depths of 1,125 feet and 2,500 feet. In this system, the drilling mechanism is suspended in the hole by cables. The unit consists of two essential parts - the drill bit and core barrel and the rotating machinery in a separate cage compartment immediately above the core barrel. The two parts have a combined length of about 30 feet and weigh about 15 tons. Power is transmitted from the motors in the upper cage to the cutting bit by means of a short drive shaft. With the heavy weight of the unit, it is necessary that a large hoist and headframe be in place to handle it. Initial cost and upkeep of this equipment is a serious consideration in the unit cost of drilling by this method. In order to prevent rotation of the drill chamber, jack screws, which can be extended against the wallrock, are built into the sides of it and thus hold the cage in place. The drilling crew consists of a foreman, one hoistman on surface, a drill runner in the drilling chamber in the hole, and one helper for each shift. Entrance and exit to and from the drilling chamber is had by means of a small cage operated by a separate hoist and cable. In this system, only enough water is put into the hole to lubricate the cutting edge, and the attachment for lifting the core out of the hole is lowered into place after the drilling equipment has been removed. Usually the hole is inspected by a man lowered in the work cage, who also cleans up any broken rock that may remain after drilling stops or after the core is removed. The hole is bailed dry by a separate bailer operated on small cable by the auxiliary hoist. Any appreciable flow of underground water that may be encountered requires special equipment for elimination prior to lowering the drilling assembly.

A variation of the above equipment has been designed to operate the drill by remote control from the surface and to eliminate the need for an operator to work in the machinery chamber.

The procedures adapted and used in the Fort Randall operation are those found successful in past experience with diamond drilling. The use of shot or a toothed bit is a variation from the use of diamonds as a cutting medium. A standard commercial diamond drill was used at Fort Randall for both drill rotation and hoisting and lowering equipment and core in the hole. The core cut by the rotating bit is pulled from the hole without the necessity of bailing or of a man's entering the hole to connect the lifting device. The use of self-contained core lifters provides for safe and speedy operation, and there appears to be little reason why similar equipment could not be used with other types of drilling rigs.



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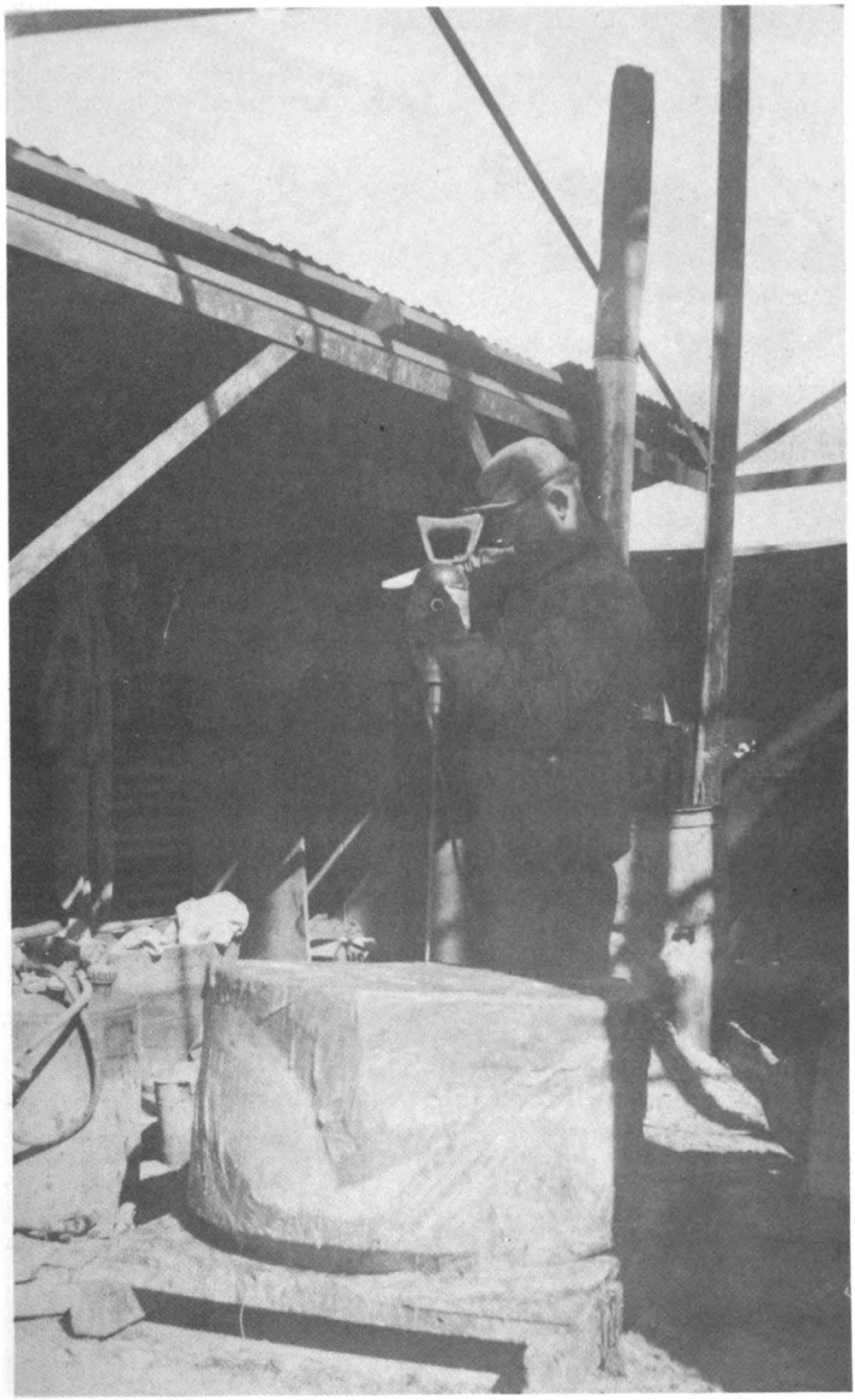

Figure 8. - Drilling dowel holes in sample section of core.

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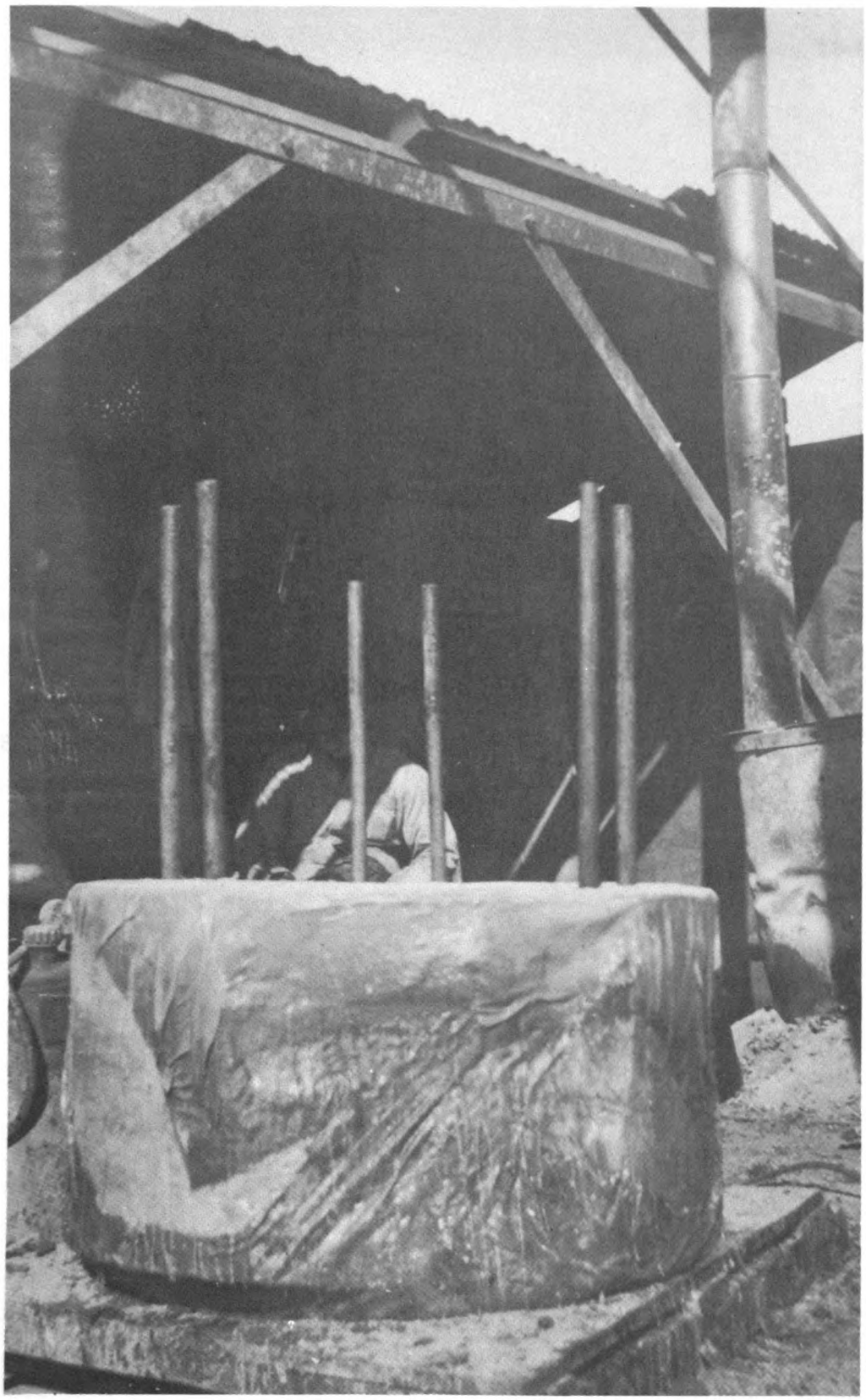

Figure 9. - Dowel pins in sample section of core.

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